Fluorescent felspar and zircon as petrological aids.

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[Taken as read March 23, 1950.]

I. INTRODUCTION.

ALTHOUGH there have been many publications on the fluorescence of minerals in ultra-violet light, very little systematic work has yet been done in utilizing this property for the elucidation of petrological problems.[1] The response of various minerals would seem to be entirely capricious; but the extensive work done on phosphors shows that this depends on the presence of traces of impurities. The spectacular display given by certain minerals has made a strong appeal to amateur collectors.

In 1943 the present writer made use of a fluorescent variety of zircon to assist in the subdivision of the Archaezoic gneisses and igneous rocks of the Musgrave Ranges in Central Australia; and after further field-work preliminary observations were published in 1947.[2]

II. TECHNIQUE.

Short-wave ultra-violet radiation (2537 Å.), as supplied by the 'mineralight', has been found most suitable for this work. In the thousands of specimens studied neither potash-felspar nor zircon gave any fluorescence under long-wave radiation 3650 Å.

1. *Zircon.*—A number of rocks have been crushed, and the minerals heavier than bromoform studied under ultra-violet radiation. This

[1] H. Haberlandt and A. Köhler, Über die blaue Fluoreszenz von natürlichen Silikaten im ultravioletten Licht und über synthetische Versuche an Silikatschmelzen mit eingebautem zweiwertigem Europium. Naturwiss., 1939, vol. 27, p. 275. [M.A. 7–530.] Lumineszenzuntersuchungen an Feldspaten und anderen Mineralien mit seltenen Erden. Chemie der Erde, 1940, vol. 13, pp. 363–386. Die Bedeutung der Fluoreszenz in der Mineralogie und Petrographie. Beiträge zur Fluoreszenzmikroskopie (special volume of Mikroskopie), Wien, 1949, pp. 102–118. [M.A. 11–158.]
W. R. Foster, Useful aspects of the fluorescence of accessory-mineral-zircon. Amer. Min., 1948, vol. 33, pp. 724–735. [M.A. 11–158.]

[2] A. F. Wilson, The charnockitic and associated rocks of north-western South Australia. Part I. The Musgrave Ranges. An introductory account. Trans. Roy. Soc. South Australia, 1947, vol. 71, pp. 195–211. [M.A. 10–438.]

method is tedious but useful, for the fluorescent grains may then be hand-picked more readily for optical and other tests. For routine investigation, however, the rock hand-specimens themselves are studied. They are held as close as possible to the source of ultra-violet radiation, and carefully observed. (It is advisable to view the specimen through plate glass to protect the eyes from reflected ultra-violet radiation).

The fluorescing zircons are revealed as tiny orange or yellow specks, scattered—usually quite regularly—throughout the rock. It is not difficult to prize a fluorescing crystal from the rock, to perform the simple optical tests necessary to distinguish zircon from apatite, which may display a similar fluorescence. In the writer's experience many more zircons display fluorescence than do apatites.

2. *Felspar.*—The pale-rose fluorescence of certain potash-felspars was first noticed by the writer early in 1949.[1] Detection of fluorescence is often only possible if the specimen is held very close to the source of the short-wave (2537 Å.) ultra-violet radiation, and the study made in a darkened room. Felspar (and to a lesser extent zircon) shows its best fluorescence when placed under the radiation from a set which has been in operation for at least two minutes. Erratic results may be obtained if the worker is impatient, or persists in switching off the set to study the rock in ordinary light. Moreover, if dry-cell batteries are used, care must be taken to ensure a reasonably constant voltage. Intensity of 2537 Å. in 'mineralight' diminishes greatly with a small drop in voltage, and this notably affects the response of many minerals. The writer prefers to use a freshly charged 6-volt accumulator.

III. Use of fluorescence phenomena in the investigation of some Central Australian rocks.

A. *Rocks from the Ayres Ranges.*

The use of fluorescent felspar and zircon may be illustrated from the results obtained in an examination of the pre-Cambrian rocks of the Kulgera Hills in the Ayres Ranges. The oldest rocks in the area are greywackes, arkoses, and quartzites. These are but little metamorphosed, and are well exposed three miles east of Kulgera Head Station. When tested under radiation of both 2537 and 3650 Å., neither fluorescent felspar nor zircon could be detected in these older rocks. In places, however, the greywackes (for example) show the beginnings of the

[1] An early observation on felspar and granite was by J. Elster and H. Geitel, Ann. Phys. Chem. (Wiedemann), 1891, vol. 44, p. 733. Records for several varieties of felspar have been given by E. Engelharat, Inaug.-Diss. Jena, 1912, and by L. H. Borgström, Bull. Comm. Géol. Finlande, 1936, no. 115, p. 354. [M.A. 6-461.]

development of porphyroblasts of felspar. In areas of more intense felspathization, numerous felspathizing veins and porphyroblasts of potash-felspar, up to 3 cm. in least dimension, were seen. This felspar displays a notable rose-pink fluorescence under intense ultra-violet radiation of 2537 Å.

Most commonly, however, the basement rocks of the Kulgera Hills are contorted sillimanite-cordierite- or biotite-garnet-gneisses of sedimentary origin. Though carefully studied, nowhere was fluorescent felspar (or zircon) seen in these, until there is a development of obvious 'secondary' felspathic veins or porphyroblasts. There is no mistaking fluorescent felspar if it is present.

Elsewhere in the area (e.g. 1½ miles west of Top Well, Kulgera), the process of felspathization has been so thorough that a rock of granite composition and appearance has been formed in situ. The relict contorted geneissic tendency of the old gneisses is still decipherable in the 'granite'. In this rock type, the felspar is notably fluorescent, but no fluorescent zircon is present.

The highly felspathized (or granitized) rocks are intruded by considerable masses of coarse to medium-grained granite. These granites have features, usually taken as field evidence of magmatism (cross-cutting characters, many with fine-grained margins; uniformity of rock mass; &c.), and it is in these that a strongly fluorescing zircon is abundant. The 'magmatic' granites, then, display both fluorescent zircon and potash-felspar.

Although fluorescent zircons did not appear until magmatic material was introduced, all igneous phases after the emplacement do not necessarily contain both fluorescent felspar and zircon. The beryl-muscovite pegmatites, for example, contain a beautiful pink fluorescent microcline, but none of the plentiful dark zircons fluoresce. Non-fluorescent weakly radioactive zircons are plentiful in similar pegmatites, which cut the parent granodioritic igneous rocks at Ernabella in the Musgrave Ranges. The parent rock of the pegmatitic zircons contains abundant fluorescent zircons (Wilson, loc. cit., p. 208). Spectroscopic analysis of these pegmatitic zircons has shown the presence of notable Fe, Mg, Al, Th, &c., and it is probable that iron, and others of these elements, may inhibit the fluorescence in these pegmatitic zircons.

Aplitic rocks are not common, but where found, are usually so fine-grained that a study of fluorescence is difficult. However, granitic aplites of this area display neither fluorescent felspar nor zircon, as far as can be determined.

In addition to these dike rocks, which are confined to the granite, there are considerable numbers of microgranitic dikes and small bosses throughout the gneissic terrains. Where phenocrysts of felspar occur, these fluoresce strongly, and some fluorescent zircon is present. This confirms the field evidence that these are micro-phases of the coarse mobilized or magmatic granites.

Study has shown that the development of crush augen-gneisses, and considerably mylonitized rocks, does not affect the fluorescence of either felspar or zircon. In the event of introduction of new material in the crush zone, the felspars (and to a lesser extent the zircon) may, of course, become affected. This may be of great value in recognizing and mapping the original rocks of a crush zone, provided that the general characters of the major rock types have been previously determined. In the Kulgera Hills, greatly crushed 'magmatic' granites can thus be readily distinguished from greatly crushed 'granitized' (i.e. non-mobilized) granites and felspathized gneisses, by the presence in the magmatic granites of both fluorescent felspar and zircon, and, in the latter group, of fluorescent felspar only.

It appears, then, that the following generalizations can be made concerning the Kulgera Hills rocks:

(*a*) *The original rocks* (both little metamorphosed and relatively highly metamorphosed sediments) contain neither fluorescent felspar nor zircon.

(*b*) *Felspathization* (with development of porphyroblasts) causes introduction of fluorescent potash-felspar, but any zircon present is non-fluorescent.

(*c*) *Granitized granites* (i.e. those formed in situ) contain abundant fluorescent potash-felspar, but non-fluorescent zircon.

(*d*) *Magmatic granites* (coarse and marginal facies) contain *both* fluorescent felspar and abundant fluorescent zircon.

(*e*) *Pegmatites* contain fluorescent potash-felspar, but the fluorescence of zircon appears to be inhibited, possibly by the concentration of certain poisoning elements in the late 'liquors'.

(*f*) *Intense crushing* has no appreciable effect on the fluorescence of either zircon or felspar.

B. *Rocks from the Musgrave Ranges.*

In a previous paper (loc. cit., p. 201), a classification of the major rock groups was suggested on the basis of fluorescence of zircons. These earlier investigations were carried out before the presence of a fluorescent felspar was suspected. The results, however, need little correction. A few gneisses, listed as non-fluorescent, display some poorly fluorescing zircons under the more intense short-wave ultra-violet radiation used in the more recent studies.

Certain gneisses (especially most of the group showing obvious sedimentary characters) contain a non-fluorescent zircon. This is usually of a pale-fawn colour, and more murky in appearance than the clear colourless fluorescent zircons of the same area (loc. cit., p. 203). Other gneisses (usually those showing a more intense felspathization) contain a small number of fluorescent zircons.

The main intrusive rock of the eastern Musgrave Ranges, the medium-grained charnockitic granodiorite of Ernabella, which intrudes all types of gneissic and granulitic charnockite, always contains an abundance of euhedral fluorescent zircons. This acidic intrusion is widespread. In its central part, near Ernabella, the importance of hypersthene and diopsidic augite, and paucity of hornblende and biotite, and other 'wet' minerals, is evident under the microscope (loc. cit., p. 206). This facies of the intrusion, though displaying abundant fluorescent zircon, contains a non-fluorescent potash-felspar (when tested under different intensities of both 2537 and 3650 Å.). In portions of the same 'batholith', and in certain 'cupola' facies, hornblende and biotite are present, instead of hypersthene and diopsidic augite, and twinned microcline takes the place of orthoclase or untwinned microcline.

A decrease, towards the east, of the pressure-temperature conditions prevailing at the time of crystallization, has enabled an increasing development of these 'wet' minerals from the Central Musgrave Ranges eastward, for one hundred miles, to the Kulgera Hills, and the attendant potash-felspar displays an increasingly intense pink fluorescence.

The following five examples[1] illustrate this gradation:

i. *Ernabella* charnockitic granites and granodiorites contain plentiful hypersthene, diopsidic augite, and non-fluorescent orthoclase or poorly twinned microcline.

ii. *Bald Hill*—a coarse facies developed in a small cupola, 14 miles ENE. of Ernabella, and containing plentiful hornblende and biotite, but no pyroxenes. Strongly fluorescent microcline is present.

iii. *Sentinel Hill*—a large granitic mass representing an 'island' of igneous rock, which crystallized under pressure-temperature conditions

[1] Fluorescent zircon appears in all non-pegmatitic and non-aplitic facies of this intrusion, and is apparently not affected by the crystallization conditions to the same degree as is felspar.

only a little lower than those obtaining at Ernabella, which is 25 miles to the WSW. Hypersthene and diopsidic augite, as well as hornblende and biotite, are well represented. The felspar is a moderately pink fluorescent microcline.

iv. *Beefwood Creek Hills* (about 50 miles ENE. of Ernabella)—the granites contain somewhat pinker potash-felspars, as seen in hand-specimen, and hornblende, diopsidic augite, and biotite are well developed. There is a notable fluorescence of well-twinned microcline.

v. *Kulgera Hills* (part of Ayres Ranges, 100 miles ENE. of Ernabella).—The granites are similar to those of the Beefwood Creek Hills, but contain hornblende and biotite, and rarely any pyroxene. A strongly fluorescent, coarsely cross-hatched microcline is present.

A similar relation between the pressure-temperature conditions, and the intensity of fluorescence in the potash-felspars, appears to hold in the case of the granulites and gneisses. The hypersthene-granulite facies contains a non-fluorescent orthoclase (or poorly twinned microline), whereas comparable rocks (of the same great system of metasediments) of the hornblende-gneisses, and biotite-gneisses, and associated migmatites, display, in the main, a fluorescent potash-felspar (usually a well-twinned microcline).

vi. *Upsan Downs granites* (25 miles WSW. of Ernabella).—These are flesh-coloured porphyritic foliated granites, similar in many respects to those of the Everard Ranges, which lie some 70 miles to the SE., across a desert destitute of rock outcrops. The potash-felspar of both granite and surrounding felspathized gneiss is notably fluorescent, but only in the mobilized granites is a fluorescent zircon present.[1] This strengthens the writer's suggested correlation of these rocks with the Everard Range porphyritic granites.

vii. *The Mt. Woodroffe–Trudinger Pass intermediate and basic rocks.*—The andesine of this great sill-like structure (loc. cit., p. 205) fluoresces a pale but distinct pink under intense 2537 Å. radiation. No fluorescent zircon is present.

viii. The *Plagioclase* of the *Basic residual lenses* in the felspathized gneisses often displays a pale but distinct pink fluorescence, but only under intense 2537 Å. radiation.

ix. Some *pegmatite plagioclases* (mainly albite) of the Sentinel Hill area and Kulgera Hills are notably activated.

[1] In the earlier paper (p. 206) it was stated that these rocks contained a non-fluorescent zircon. Under the more intense 2537 Å. radiation now in use, the zircon is activated.

The significance of the comparable fluorescence of both plagioclase and potash-felspar is as yet unknown. Since the two mineral species have a similar structure, it is conceivable that the one activator could give a similar fluorescence in both minerals. It is suggested, however, that the activator (? rubidium or caesium) is associated with the potash-felspar phase in the exsolution antiperthites of these rocks. This could account for the relatively weak fluorescence of certain plagioclases in the gneisses and granulites, when compared with that of the potash-rich felspars.

IV. Some other examples of fluorescence phenomena.

A. *South Australia.*—Strongly fluorescing microclines are a feature of the Murray Bridge and Goonalpyn fluorine-rich granites, and of the Minnipa-Wudinna granites on Eyre Peninsula. There are several other important granites and felspathized gneisses. In addition, apatite, fluorescing in orange, is important in many Boolcoomatta and Mt. Painter granites, as well as the pegmatites of the eastern Mt. Lofty Ranges.

B. *Other Australian States.*—From a study of over one thousand museum specimens, it appears that in each State several granitic areas occur in which fluorescence of felspars is a feature. There are other granites which display no fluorescence. It is suggested, therefore, that critical work on carefully collected material should prove of considerable petrological value in any of the Australian States.

C. *European and American* granitic specimens were studied with similar results. Examples with notable fluorescent felspar are Shap Fell, England; Peterhead, Scotland; most of those of the Odenwald, Germany; &c. Some of those displaying no fluorescence are many Cornish granites; Ramberg, Harz Mts., &c.

V. Conclusions.

It is apparent that the pink fluorescence of the potash-felspars is a widespread phenomenon, as also is the orange fluorescence of both apatite and zircon. Nevertheless, there are sufficient rocks, which do not display any fluorescence, to make a study under ultra-violet radiation a valuable aid in petrological research. Since, however, the indiscriminate use of fluorescence can lead to misleading results, the following principles should be understood, before the phenomenon is used for this purpose:

1. Fluorescence is often due to a trace element (or elements) which

appears to distort the structure of a mineral. This substance, the activator, can be detected only with great difficulty, even spectroscopically, in natural substances.

2. Too much of the activator can 'quench' any fluorescence.

3. The presence of other elements (e.g. iron) may act as 'poisons' and thus inhibit fluorescence. The application of these principles is seen when a mineral (e.g. zircon), which is normally fluorescent in a certain area is non-fluorescent in some associated pegmatites. The mineral has presumably picked up from the pegmatitic 'liquors' certain 'poisoning' elements, so common in such an environment. It is, therefore, unwise to attempt a correlation of pegmatites by fluorescence alone.

4. The petrological use of fluorescence is most significant in the examination of rocks of pre-Cambrian or early Palaeozoic areas. The basement rocks of such terrains often contain no fluorescent minerals. In younger rocks second (or later) generation fluorescent minerals may be found, and the phenomenon may be very confusing. It is important, therefore, to spend time in a preliminary study of the oldest rocks of an area before attempting to make use of fluorescence correlations.

5. The conditions under which crystallization is effected may have a considerable bearing on fluorescence. In a major intrusion deep-seated areas may show features different from the cupola or marginal facies (e.g. Musgrave Ranges, Central Australia). This may be due to the inability of the activators (even if present) to enter into the structure under the high pressures and temperatures prevailing at the place of crystallization. Felspars seem to be more sensitive than zircons or apatites in this respect. Empirically, there appears to be a relation between the intensity of felspar fluorescence and the coarseness of the twinning in microcline. The variability of the cross-hatched twinning may be due to varying amounts of activator ions (and possibly other trace elements) in the felspar structure. Some of these, by virtue of their ionic volume, may have facilitated the development of a coarsely cross-hatched twinning, either on the inversion of a pre-existing orthoclase, or in a primary microcline. In most pegmatites the pressure-temperature control is such that more of the abundant volatiles and trace elements is able to be incorporated into the complex structures. Many of these ions, however, may be in excess of the minute quantities required to give the optimum fluorescence, and others may act as 'poisons'.

6. The above factors indicate that only those rocks which show similar pressure-temperature conditions and similar composition should

be compared by fluorescence of minerals. For instance, granitic aplites should not be compared with charnockitic granites, nor biotite-microcline-granite with hypersthene-orthoclase-granite, nor even similar facies granites and gabbros.

It is considered that if fluorescent data be carefully assembled in connexion with each petrological problem, not only will much of immediate value be derived, but the increasing world-wide accumulation of facts will allow more accurate deductions and correlations to be made.

Acknowledgements.—The research recorded in this paper was carried out in the Department of Geology, University of Adelaide. The field-work was made possible by a Commonwealth Research Grant, administered by that University. Professor Sir Douglas Mawson, Messrs. A. W. Kleeman, and H. Brock of Adelaide, and Professor R. T. Prider of the University of Western Australia, have read the manuscript and made useful suggestions.